RESPONSE OF TRANSPLANTED ASPEN TO DRIP IRRIGATION ON RECLAIMED MINE LANDS

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Response of Transplanted Aspen to Drip Irrigation on Reclaimed Mine Lands

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Project Abstract

Successful re-establishment of aspen on surface-mined lands in the western United States is problematic, because the species regenerates vegetatively by sprouting from parent roots in the soil which is removed in the mining process. Previous attempts to plant aspen seedlings on reclaimed mines have failed because transplanted root sprouts or seedlings do not have an extensive root system to access water and nutrients for rapid growth. This research builds on work previously funded by the Seneca Coal Company in western Colorado to identify factors that limit the growth and survival of planted aspen. The use of supplemental irrigation to help establish planted aspen was tested; and growth and survival of three types of aspen stock on two soil types were compared. Soil and water conditions were monitored, and the effect of weed control on planting success was examined. The best combination of conditions for reproduction of aspen on reclaimed surface mined coal lands uses transplanted saplings from local sources on freshly placed soil removed from aspen stands. Growth was significantly higher when weeds were controlled around individual trees. Irrigation with non-saline water may enhance growth and survival in years with drought conditions.

Regional Special Interest Topic:
Wildlife Conservation and Reforestation

Reforestation—Improving survival and quality, and encouraging reforestation

Project Description

Objectives:

1. Determine if supplemental drip irrigation will allow transplanted aspen saplings to survive and grow on reclaimed surface mined lands at a western Colorado site.
2. Quantify second and third-year growth and physiologic condition of bare-root saplings transplanted to replaced topsoil, aspen sprouting from root segments transferred with replaced topsoil, and nursery-grown potted aspen saplings planted in replaced topsoil.
3. Compare irrigation water quality and characteristics of replaced topsoil to that of water and soils in intact aspen groves located on adjacent un-mined lands.
4. Quantify the effects of mechanical weed control on growth and survival of young aspen trees.
5. Quantify root growth and development of transplanted aspen saplings, natural root sprouts, and nursery-grown potted aspen seedlings after three growing seasons.

Background:

Quaking aspen (*Populus tremuloides*) is the most widespread tree species in North America (Baker 1925; Preston 1976; Lieffers and others 2001), and thought to be second in worldwide range only to Eurasian aspen (*Populus tremula*) (Jones

1985a). Aspen is found in most of eastern Canada and the U.S. (except the Southeast), throughout the upper Midwest and Lake States, across sub-boreal Canada and Alaska, in the Rocky Mountains from Canada through the U.S. and into northern Mexico, and in mountain ranges paralleling the west coast from Alaska through British Columbia, Washington, Oregon, California, and Mexico's northern Baja California (Preston 1976). The species is most abundant in Canada's central provinces and the U.S. states of Colorado and Utah (Jones 1985a; Lieffers and others 2001). In much of the western U.S., aspen is a mid-elevation shade-intolerant species which is a relatively minor component of more widespread conifer forests.

Aspen is an important tree species throughout the western United States. One of the few broad-leaved hardwood trees in many western forests, it is a valuable ecological component of many landscapes, occurring in pure forests as well as growing in association with many conifer and other hardwood species. Aspen provide desirable scenic value, the diversity of plants growing under aspen supply critical wildlife habitat, valuable grazing resources, protect soils from erosion, and help maintain water quality. These features make aspen a crucial component of many Western landscapes.

At the continental scale, aspen has several physiological characteristics that permit it to attain great geographic amplitude. Lieffers and others (2001) outline the following important adaptive traits of aspen: 1) among the wide ranging genus *Populus spp.* (cottonwoods, poplars, aspen) aspen seems to have a very high stress tolerance. Usually high stress tolerance is associated with slow growing species and those with a limited reproduction strategy; 2) aspen appear to rely on vegetative reproduction via root suckering more than other *Populus* species. These authors assert that the passing of extensive root systems between generations enhances tolerance to absorb climate stress (DesRochers and Lieffers 2001); 3) Aspen also has the ability to adapt leaf size to xeric and mesic conditions (that is, smaller leaves for drier sites). Aspen's smaller leaf size could keep the leaf surface slightly cooler allowing earlier shut down of stomata, thus tempering water stress during drought; 4) aspen seem to tolerate cold temperature and short growing seasons better than most hardwoods (Pearson and Lawrence 1958); 5) leaf fluttering may be an adaptive advantage in cooling leaf surfaces of many *Populus* species and, 6) aspen appear to have a higher photosynthesis capability than other *Populus spp.* which is comparable to that of high yield poplar hybrids. Aspen photosynthesizes well in low light (for example, competitive situations) and even mature bark is capable of photosynthesis, which helps to ameliorate respiration during periods of high insolation (before spring leaf-out) (Pearson and Lawrence 1958). Photosynthesizing bark may help aspen recover from injuries and infestations (Jones and Schier 1985; Lieffers and others 2001) and may allow aspen to photosynthesize at low levels during the winter giving the tree a photosynthetic "boost" prior to leaf-out (Pearson and Lawrence 1958; Shepperd and others 2004). As leaf chlorophyll increases during the summer, bark chlorophyll decreases causing bark to become whiter (Strain 1964).

Although aspen does produce abundant crops of viable seed (McDonough 1979), it primarily reproduces vegetatively by root suckering throughout most of its

western range. Occasional seedlings do establish, but seedlings require bare mineral soil and constant moisture to survive (McDonough 1979). These conditions rarely occur in many of the areas where aspen grows today. Aspen typically grows in genetically-identical groups referred to as clones. All stems in a clone sprouted from the roots of parent trees and share a common ancestor. However they do not share a common root system, as connections break down from generation to generation as new trees grow new roots.

Most aspen stands are composed of one to several clones that may persist along a continuum of successional stages, from sparsely growing individuals to apparently stable pure or near-pure groves. Although clones are often separate and distinct from one another, studies have demonstrated spatial intermingling where multiple clones are co-located (DeByle 1964; Mitton and Grant 1980; Wyman et al. 2003; Hipkins and Kitzmiller 2004).

Compared to conifers, aspen ramets – individual stems, or suckers, of the same genotype from a parent root system - are relatively short lived. This is due to succession (replacement of aspen by more shade tolerant species) and/or a typical onslaught of mortality related to stem decays and diseases from ages 80 to 100 years (Baker 1925; Hinds 1985; Potter 1998; Rogers 2002). Aspen thrive where somewhat regular and frequent disturbance promotes regeneration (DeByle and Winokur 1985). Occasionally aspen stands appear to perpetuate themselves with regular low-level regeneration in multi-layer stable stands (Mueggler 1988; Cryer and Murray 1992). Aspen in the western U.S. are longer lived than elsewhere. Healthy aspen trees can live over 300 years (Personal Comm., John Shaw, Forester, USDA Forest Service, Rocky Mountain Research Station) and attain diameters of at least 38 inches (96.5 cm) diameter at breast height (dbh), however most aspen are typically much younger and smaller. Many mature stands in Colorado are currently over 120 years of age (Shepperd 1990). Tree form varies from shrubby at upper and lower forest margins to over 100 ft (30.5 m) in height in prime locations with average heights of 50 to 60 ft (15 to 18 m) (Baker 1925).

Vegetative regeneration of aspen requires the interruption of the auxin/ cytokynin hormone balance between roots and shoots to stimulate root buds to begin growing (Schier et al. 1985). This hormonal imbalance can result from any disturbance that interrupts the flow of auxin from photosynthesizing leaves to a tree's roots. This can result from disturbances that kill the parent trees outright, such as a fire, disease, and timber harvest, or from disturbances that only temporarily defoliate the parent tree, such as a late frost, defoliating insect attack, or light herbicide application. Severing lateral roots from parent trees can also initiate suckering, as would occur when fire, burrowing animals, or other factors kill portions of a lateral root. The sucker initiating process has been referred to as interruption of apical dominance (Schier et al. 1985.).

In any case, the initiation of bud growth must also be accompanied by sufficient sunlight and warmer soil temperatures to allow the new suckers to thrive (Navratil 1991, Doucet 1989). Full sunlight to the forest floor best meets these requirements. However, young aspen suckers are susceptible to competition from other understory plants and herbivory from browsing ungulates, even if abundant suckers are present.

Having access to a well developed parental root system gives aspen sprouts a great advantage over other plants. The parent roots supply carbohydrates and access water deep in the soil profile allowing sprouts to grow rapidly, out-compete other vegetation, and withstand frequent droughty conditions in the West.

Re-establishing aspen on surface-mined lands is therefore problematic, since the parent root systems are destroyed when topsoil is removed. Planting aspen in a non-irrigated location in a Colorado study was not successful (Shepperd and Mata 2005). Transplanting greenhouse or nursery-grown aspen seedlings into the field has similar problems to those of natural seedlings, indicating that the small root mass of transplanted seedlings is insufficient to absorb enough moisture to maintain the seedlings during periods of summer drought in the wild.

In contrast, transplanting sapling-sized aspen in irrigated urban landscapes has not been a problem, because the abundant supplies of water in lawns and landscape beds enable the transplants to thrive. Although aspen is somewhat tolerant of drought conditions (Lieffers et al. 2001), irrigation could benefit growth and survival of planted aspen stock, because moisture stress negatively affects aspen response to nutrient uptake (van den Driessche et al. 2003). Water deficit stress also reduces stomatal conductance, root hydraulic conductivity, and shoot leaf water potential in aspen (Siemens and Zwiazek 2003). Irrigation has been shown to increase growth of hybrid poplar, a closely related species (Hansen 1988; Strong and Hansen 1991).

Therefore, it seems reasonable to conclude that supplemental irrigation of aspen planted on reclaimed surface-mined lands could increase initial survival and allow trees to grow sufficient root systems to ultimately survive without additional water and establish new self-regenerating clones on mined lands. Testing this hypothesis, gaining additional knowledge about different planting methods, and documenting factors that potentially limit the re-establishment of aspen is crucial to re-establishing aspen on surface-mined lands in the arid west. This research was a collaborative three-year effort, with 2005 and 2006 funding from Seneca Coal Company; and 2007 funding from Seneca Coal Company and OSM-NTTT. The US Forest Service contributed cost share funding for the project 2005-2007.

Preliminary Studies:

A pilot study was funded by Seneca Coal Company in 2004 to examine the feasibility of using supplemental drip irrigation to establish aspen on reclaimed coal mine overburden soils. Overburden and top soils are normally stored for a number of months before landscape resurfacing and planting. The study, established on re-claimed lands owned by Seneca near Hayden, Colorado (Figure 1), examined for the 2005 and 2006 growing seasons the growth, survival, and water status of aspen trees planted on reclaimed soils during the fall of 2004.

The objective of this study initially was to examine the survival, growth, and water status of irrigated aspen transplants on two types of topsoil, placed over coal mine overburden material that had been replaced after surface mining. However, circumstances allowed us to expand the original study design to collect growth and survival data from: 1) aspen sprouts transplanted from a nearby mine, placed in two topsoil types within a fenced area and drip irrigated at three watering levels

with an un-watered control; 2) un-watered sprouts arising from aspen root segments that had been transported into the fenced area in the two top soil types; 3) commercially grown potted aspen seedlings that were planted in a nearby fenced area, and; 4) natural aspen sprouts growing in an un-mined area in the vicinity that was not fenced and subject to grazing effects of ungulates on growth and survival of aspen sprouts.

Design and Methods - The initial project was a case study of the effectiveness of irrigation treatment on the survival, growth, and water status of aspen cuttings planted on a site of reclaimed land of the Seneca Coal Company II-W mine south of Hayden, Colorado. The irrigated portion of the study was designed to measure the effect of supplemental irrigation on aspen saplings that had been transplanted from a naturally regenerating un-mined site on the nearby (<3 km) Yoast mine where the original forest was being cleared in preparation for mining. Aspen saplings between 1-2 m in height were selected from this site at the end of the growing season in 2004 and pruned to leave only the uppermost branches intact. In October, 2004, these saplings were dug using a small backhoe and immediately transplanted into augered holes that had been prepared at the fenced planting site at the II-W mine. All cuttings were presumed to be from the same genetic clone since they were collected from the same area. Trees were planted in eight blocks consisting of five rows of ten trees, (50 trees total) spaced on a 1.5 m x 1.5 m grid (Figure 2). Four blocks were placed in each of two types of topsoil that had been removed from areas being prepared for surface mining.

Roto-cleared topsoil had the original vegetation on the site chopped and mixed into the top 4 inches of topsoil prior to removal and replacement on the plantation site. Dozer cleared soils had all above-ground vegetation bladed aside for disposal prior to removal and storage before replacement on the plantation site. The dozer cleared soil used in this study had been stored for a few months, as indications of decay were present and few weeds initially grew in this soil. Both soil types were from aspen stands, contained aspen roots and were placed to a depth of approximately 1 m on the plantation site. The soils were spread by scraper in the late summer of 2003, and were final graded in May/June of 2004, prior to aspen planting in October, 2004.

Water was delivered during the 2005 growing season by drip irrigation to the transplanted aspen saplings via a computer-controlled system that timed the daily application of water through calibrated emitters. The four water treatments (high, medium, low, non-irrigated control) were randomly assigned to one of the four blocks in each of the two soil types, with all 50 trees in each block receiving the same amount of water (Figure 2). A gravity fed drip system, supplied by a 2000 gallon tank located 207 vertical feet upslope from the test site provided an adequate head to maintain water pressure greater than 60 lbs in all lines. The tank was filled by Seneca Coal Company workers as needed, generally once or twice a week. Source of water was a sedimentation pond lower in the reclaimed watershed. Drippers delivered water at 1 gallon/minute, and were programmed to deliver water daily at 1.3, 0.6, and 0.3 gal/day/tree for the high, medium, and low irrigation levels; equivalent to 14.4, 7.2, and 3.6 inches of precipitation per month. The non-irrigated control received no supplemental water. Irrigation treatments

were applied daily during the early morning. Drippers required 4 lbs pressure for activation; the valve box and distribution lines were configured so that head pressure down stream of the valves did not exceed this value to avoid leakage between irrigation treatments. Soil moisture and temperature sensors were located in each plot and data were recorded hourly. Standard meteorological conditions were monitored at an automated weather station located at the center of the plot, and data recorded hourly included wind speed, wind direction, relative humidity, and precipitation. Hourly soil temperature, moisture content, and matrix potential were also monitored at one tree in each watering treatment. All data were recorded on a Campbell 23x data logger, which also was programmed to activate the irrigation solenoids. Power was supplied from 12 V batteries charged by a solar panel.

In addition to the watering study, growth and survival data were obtained from three other types of young aspen trees: 1) Natural sprouts that had grown from roots buried in un-irrigated areas of the roto-cleared and dozer-cleared soil adjacent to the irrigated blocks; 2) commercially-grown potted aspen seedlings that were planted in an unirrigated fenced area approx 1 km from the irrigation study site, and; 3) natural aspen sprouts growing in an un-mined area of the Yoast mine that had been cleared of mature aspen. None of these study sites were replicated, so the survival, growth, and water status findings are applicable only for that site; and comparability of different un-replicated treatments within the same site must be made with caution. Although the commercially-grown potted aspen trees were planted on dozer-cleared soil, it was not determined if the roots grew out of the potting mix into the dozer-cleared soil during this first year of study.

Natural sprouts were growing at random spacing, about 1 ft to 8 ft apart. Natural sprouts selected for measurement were thinned to no closer than 5 ft spacing. The potted and natural trees in all locations were from unknown genotypes, likely different from the irrigated study transplants. The natural sprouts on the roto-tilled soil were all likely from the same genotype since the soil came from the same area; but they were likely different from those on the dozer-tilled soil. Similarly, the natural sprouts on the dozer-cleared soil were possibly from the same genotype.

Data Collected - Prior to bud break, height of each tree, number of branches, disease and insect infestation, and length of terminal leader dieback was recorded for each tree. Water status and tree growth were measured periodically throughout the experiment. Physical measures of growth were height (cm), basal caliper (mm), number of basal sprouts (count), length of the terminal leader (cm), and length of each of the next three sprouts on upper portion of tree (cm). Disease and insect infestation were recorded again at the end of the growing season.

Water status, or leaf water potential, of the plants was measured on June 22, July 21, and September 20 as near to dawn as possible (½ hr predawn to ½ hr after sunup) to capture the minimum stress before rapid morning transpiration has depleted leaf moisture. One afternoon measurement was also conducted on August 18 to indicate maximum stress under high radiation loading when transpiration would be highest. Treatment, ambient temperature, time of sampling

and exuding pressure level was recorded. Leaves were collected from the different treatments at random to minimize time of sampling biases.

Leaf water potential will increases as water is withheld from the plant and plant water stress increases. Water status measurements required removing one fully matured leaf randomly selected from trees in each treatment and measured for water holding capacity using a Plant Water Status Console. The leaf was removed from the plant and immediately placed in a sealed chamber with the petiole extending through a sealing hole in the chamber. A fresh slightly angled cut was made and nitrogen gas was delivered to the leaf under slowly increasing pressure until water exudes from the petiole surface. The pressure necessary for this to occur is an indication of the leaf water potential or water holding capacity of the leaf, an indication of the water stress and thus physiological stress of the plant. Different plants from each treatment were selected at each testing to minimize leaf loss from sampling. From 2-3 total measurements were made from each treatment each day of measurement. Number of measurements depended on the time necessary for each measurement, so that all measurements fall within the dawn-time window. Each day of measurements included leaves from all irrigation treatments. Size of sampled leaf was recorded as length from tip to petiole (mm), and maximum width (mm). An empirical equation was developed to relate width and length to actual leaf area.

Results (2005-2006) - The first two years of the study have provided significant results worth reporting here. Supporting data have been presented in earlier reports. The study was initially conducted to demonstrate the effectiveness of supplemental irrigation on growth and survival of transplanted cuttings; but additional experimental conditions allowed examination of additional factors. Factors examined in the experiment were: irrigation (four levels of watering), soil type (roto-cleared/fresh, dozer-cleared/stored, or undisturbed), plant type (transplanted rooted sprouts, natural sprouts, potted plants) and fencing (fenced or not fenced). Since not all treatment combinations existed and none of the treatments were replicated, statistical analyses and inferences are limited. For example, differences in growth or survival between Yoast, II-W roto-cleared soil sprouts, and II-W irrigated treatments may be due to differences in soil disturbance, genetic stock of aspen, transplant type, fencing, or microclimatic differences between sites, treatments not independently replicated for this study. This study was considered a case study relevant only for this one location. Nevertheless, several observations were evident from the study that might be helpful for future aspen management and to identify areas for additional research.

I. Irrigation treatment - For this experiment rainfall was plentiful and not typical for the first two years during the study and soil moisture was relatively high even in un-irrigated plots, as indicated by soil moisture matrix potential values and low leaf water potential data for all treatments. This prevented a good examination of the irrigation treatment effects. Aspen growth and survival did not appear to be dependent on, or in some cases consistent with, irrigation treatment, suggesting that soil moisture from the frequent rain events was sufficient even in the non-

irrigated plots. The supposition of adequate moisture available to all trees is further evident in that there appeared to be no relationship between irrigation treatment and average leaf area, total leader growth, terminal leader growth, stem diameter growth or caliper, or survival (data previously shown in earlier reports). Growth of second, third, and fourth lateral branches appeared to be similar for all treatments, but are reflected in total growth. Pre-dawn leaf water potential levels also indicate moisture stress was generally less than 8 bars (0.8 mPa) pressure, and did not appear to be related to irrigation treatments during the years when these measurements were taken.

II. Transplant type - The aspen saplings used in the irrigation study that were transplanted from the Yoast site exhibited considerably more injury and had considerably more disease infections than natural sprouts arising from buried root segments or potted plant. Transplant shock was evident only the first year. Leaf area growth, leader growth, stem diameter growth, and survival were considerably less with these plants than with natural sprouts or potted plants during the first year of the study, but the transplanted trees grew well the second and third year of the study (depending on treatment). Potted plants survival was 100% and growth on these trees appeared better than transplanted cuttings the first year. Growth of the transplants was better than potted plants in subsequent years.

III. Soil type –Roto-cleared soil provided sufficient natural sprouting to provide an adequate stand of aspen trees, and these trees appeared to grow better and survival appeared higher than adjacent transplanted trees growing in the same soil in the first two years of the study. Dozer-cleared soil which had been temporarily stored, had considerably lower numbers of natural sprouts than roto-cleared soil, and stocking was sparse (data not shown). Natural sprouts appeared to have greater total leaf area and greater stem diameter growth on roto-cleared soil than dozer-cleared soil, but terminal leader growth appeared similar on both soil types (data presented in earlier reports). Natural root sprouts had no lateral branches. Leaves also appeared to be larger on these trees (data not shown). Nevertheless, these trees apparently experienced somewhat greater pre-dawn water stress in July and September than trees in the irrigated treatments, including the irrigated controls with no water added. The data suggest that pre-dawn water stress levels as high as 14 bars, and afternoon water stress levels as high as 20-25 bars, were not of sufficiently high levels to cause enough stress to reduce survival or growth of these trees.

Soil moisture stress appeared to be less with transplanted sprouts in the irrigation experiment, including the un-irrigated controls, than with natural root sprouts or potted plants. It is interesting to note that leaves appeared smaller and terminal growth appeared less on these apparent less-stressed transplanted trees, suggesting that growth of root sprouts, potted plants, and natural sprouts was not limited by the apparent higher moisture stress levels they experienced. Maximum leaf water potentials at mid-afternoon found stress levels of about 25 bars or less, levels that appeared unrelated to treatment, or to growth and survival.

The growth data suggest that roto-cleared soil could have provided additional nutrients or other benefits, perhaps mycorhizae, for tree growth. Weed growth appeared greater on roto-cleared soil than dozer-cleared soil (data not shown).

IV. Fencing - Fencing is necessary to obtain an adequate stand of aspen, regardless of the sources of the trees. The unfenced Yoast site had severe damage from ungulates, including breakage of stems, browsing, and rubbing damage. Most trees at this site had some form of injury. Yet, growth and survival of these trees was good, suggesting that the undisturbed soil presence of an extensive parent root system is ideal for growth of aspen. Nevertheless, fencing of these trees is recommended to produce an adequate stand of mature aspen.

Conclusions (2005-2006):

I. Growth and survival did not appear to be related to irrigation treatment, likely a consequence of the high rainfall during the 2005 and 2006 growing seasons.

II. Best growth appeared to be on natural root segment sprouts on roto-cleared soil for the first year. Transplanted trees grew well after the first year's transplant shock.

III. Transplanted sprouts showed considerable transplant injury their first year, regardless of irrigation treatment in this relatively wet. Growth and survival was relatively low and diseases were higher in transplant cutting plots compared to natural sprouts and potted plants. Recovery of surviving transplant trees was good and growth was good the second year.

IV. Potted aspen from nursery stock planted on dozer-cleared soil grew well and had high survival the first year.

V. Fencing is necessary to protect small aspen trees from browsing injury.

Experimental Procedures/Methodologies for 2007:

Study Design: Based on the important finding for 2005-2006 summarized above, several new questions regarding aspen growth and survival on reclaimed lands arose, and follow-up research was conducted using the same II-W Mine plots where the 2005-2006 study was conduced. Our intention was to utilize the existing study design and sampling regime to collect third year survival and growth data from trees sampled in 2005-2006. OSM funding was used for data collection during 2007 and for data analysis and preparation of the final report. Details of operation of the irrigation system, types of planted aspen studied and sampling procedures remained as previously described. Deviations and additions to the original study design are described below.

<u>Irrigation Treatments:</u> Based on findings from 2005 and the higher than normal rainfall, irrigation treatments were applied differently during the 2006 and 2007 growing seasons. Treatments were applied at 0.0, 0.15, 0.3, or 0.6 gallons each day of treatment, one-half the rate applied in 2005. Irrigation treatments were to be continued throughout the growing season. Because of evidence of saline condition

of the irrigation water supply during 2005 - 2006, clean potable water from a Hayden, CO, hydrant was used to irrigate the trees in 2007.

Growth of transplanted rooted sprouts in the second and third year: Some of the transplanted aspen in the irrigation plots had apparent dead tops after the first year. It was expected that some of these could grow back from root sprouts. We examined survival and re-growth of these trees that died back from injury or disease the first year. It was expected that surviving plants would do well in the second year following first year transplant shock. Survival and growth in the third year would enhance long term survival. Growth and survival of natural sprouts and potted plants were also examined in the third year to provide an indication of possible long-term survival.

Differences in soils: There were rather dramatic differences between the two soil types for many of the attributes measured in 2005. As such, it was important that differences between the two soil treatments be fully described. Soil samples from the two treatments were collected and analyzed for organic matter and nutrient content, water holding capacity, chemical, and physical properties. Since the soils were mixed and soil horizons present in normal soils were missing, integrated samples were collected through the entire surface soil profile, approximately 0.75 to 1 m depth. Soils were analyzed for soil texture and fertility (organic matter, pH, N, P, K, CEC). Bulk soil samples were periodically collected and oven-dried for soil moisture determination.

Given the growth differences observed on the two soil types in 2005, it was important to quantify how the replaced soil differs from natural soils on the Seneca II-W Mine. Samples of undisturbed soil were collected under aspen stands in undisturbed areas of the mine and subjected to the same analysis described above. In addition, differences in soil conditions between reclaimed soils in the study area and those under nearby undisturbed aspen clones were quantified by comparing physical and nutrient characteristics of soil samples from both the normal and augmented reclaimed soils to those of the natural soils. Sampling of the soils under nearby native undisturbed aspen stands were extended to the same depth investigated in the reclaimed soils on the study plot. Effects of reclamation on soil moisture regimes were investigated by monitoring soil moisture during the growing season in undisturbed clones to that of un-irrigated portions of the study site.

Discussions with Seneca Coal Company document that the roto-cleared soils had been moved directly from its original site to the plot site; while the dozer-cleared soil placed at the experimental site was from a soil storage site where it had been stored for several months. The difference in response of aspen tree growth between the two soils types was expected to be primarily due to storage rather than to method of tree removal. Stored soils were observed to be anaerobic.

Water Chemistry: White salt deposits were observed around some of the irrigated treatments in 2005, particularly those trees receiving the high irrigation treatment, leading to the question of whether these salts were leached from the re-

deposited topsoil, or were present in the irrigation water. The soil chemistry tests conducted included a salinity analysis. Soils analyses confirmed that the soils with the highest rate of irrigation were indeed saline, likely the result of irrigation with saline water. Only clean water was used to irrigate the trees during 2007 to avoid further decline and to see if the trees irrigated with saline water could recover. Root zone soil samples were also submitted to the soils testing laboratory for determination of saturated paste extract conductivity.

Root growth: Aspen is a relatively short-lived disease and injury susceptible tree that relies on periodic re-sprouting from lateral roots to maintain its presence on a site (Shepperd 2005). Therefore, the development and lateral extension of new roots is critical for the ultimate survival and re-establishment of any aspen planted on mined lands. We quantified new root development since planting by excavating randomly selected surviving plants during 2007, washing soil from the roots to quantify total root biomass and new root growth. Trees were chosen from each of the different irrigation, soil, and transplant treatments studied. Soil was carefully loosened and roots exposed by washing soil away with a high pressure water jet. Once roots were exposed, the spread of any lateral roots away from the planting site was measured as distance from the tree base and as total length of each root. Root masses were separated by size class and total below-ground biomass dry weight was measured. It is particularly crucial to see if roots have extended beyond the planting hole for transplants or beyond the potting mix for potted aspen. This root extension is necessary for survival of the trees and the ultimate re-establishment of natural aspen clones. Roots must also reach a large enough size, and be close enough to the surface, for suckering.

Physiological status: Monitoring of leaf water potential during 2005, a wet growing season, indicated that varying irrigation treatment did not affect leaf water stress condition of the plants. However, additional physiological conditions of the plant that affect growth and survival were unknown. Other physiological conditions, such as stomatal conductance, photosynthesis, and respiration, may show response to drought prior to indication by plant water status; or at the least indicate which trees are stressed and not likely to survive. Therefore, we collected limited additional physiological measurements of the transplants under each irrigation treatment, including photosynthesis, respiration, and transpiration. This would allow a better evaluation of the physiological stress conditions occurring under specific irrigation treatments; and the physiological conditions favorable for survival.

Competing vegetation: Invasive annual weeds including tumbleweeds and thistles were common in the plantations in 2005 and 2006, as well as numerous native herbaceous species. We controlled competing vegetation in the irrigation and root-sprout treatments by repeatedly hoeing and cutting all weeds growing around study trees. Landscape fabric placed around potted trees when they were planted prevented weeds from growing next to those trees. The aggressive nature of weeds suggests that vegetative competition may be important in survival and

growth of aspen trees. The inability of easily controlling competing vegetation with herbicides around broad-leaved species like aspen presents additional constraints. We investigated this question by continuing to mechanically control competing vegetation around trees in half of each irrigation and soil treatment. Treatments in the fenced plantation area were divided into sections to be weeded and sections not weeded. The two weeding treatments were superimposed on the existing study design; and growth, physiological parameters, and survival were compared as in other treatments. Soil samples were collected from each treatment for moisture content analysis.

Experimental Results:

Aspen growth and survival on reclaimed lands was successful under certain conditions. The experiment was conducted 2005-2007 on the II-W Mine plots, Seneca Coal Company, near Hayden, CO (Figure 1). This report examined third year growth and survival of these trees.

<u>Growth by irrigation treatments and plant type:</u>

Saline water inhibited the growth of aspen on high and medium irrigation treatment plots the first and second year of the study. These trees were still smaller in the third year but their annual growth had nearly recovered to that of low and control irrigation treatments (Figure 3). Growth of the low irrigation and control (no irrigation) treatment trees was higher than that for the high and medium irrigation treatments suggesting that the reduced growth from the saline water used for irrigation in the first and second years of the experiment was still evident in the third year of treatment. Nevertheless, growth of these trees was still greater than that for the natural sprouts and potted trees. None of the trees that had died in previous years re-sprouted from residual roots in 2007. Since growth of aspen was good with the low and no irrigation treatments, it is evident that there was sufficient natural rainfall during the three years of the study for the trees to survive without irrigation. It is possible that growth under the high irrigation treatment could have been higher than the lower irrigation treatments had clean water been used. The benefit of clean water irrigation of newly planted trees under more normal, low rainfall conditions could not be determined in this experiment since low rainfall and drought conditions did not occur during the study.

Growth of the transplanted trees was generally good during the third year of treatment and surpassed that of the natural sprouts and potted trees (Figure 3). Survival was similar for all transplants and natural sprouted trees (50-57%), but was considerably higher for potted plants (80%). Growth and survival of the potted trees was excellent the first year of the study, but after three years growth of the potted trees remained relatively stagnant and these trees were considerably smaller than the transplanted trees. Growth of natural sprouts was also less than transplants after three years.

Differences in soils:

There were rather dramatic differences between the two soil types for many of the attributes measured in the experiment, particularly growth (Figure 4). Soil samples from the two soil types were collected and analyzed for organic matter and nutrient content, water holding capacity, chemical, and physical properties. Because the soils were somewhat mixed prior to placement and no soil profile existed, sampling at 1 foot increments was not conducted. Samples analyzed were taken from the entire topsoil depth placed at the site, about 1 m deep. Preliminary data indicate that neither soil type was toxic, except for high electric conductivity in high irrigation treatments for 2006. Nutrient content such as nitrogen did not seem to be related to soil type, and appeared to not be the limiting factor in tree growth.

Fresh roto-cleared soils provided adequate sprouting of aspen from residual aspen roots in the topsoil. Limited sprouting occurred from the stored dozer cleared soils. The data suggest that moving fresh soil to reclaimed land could allow for sufficient sprouting of aspen from residual roots without planting. While survival was not significantly different on the roto-cleared (53%) and dozer-cleared (52.5%) soils, average growth on dozer-cleared soils (18.9 cm) was only about two-thirds of that on the roto-cleared soils (29.4 cm).

Dozer cleared soil had higher moisture content, suggesting either less ability of the trees to extract the moisture since they were smaller, and/or the dozer cleared soils had better soil moisture holding capacity and/or was less well drained. Visual observations suggested that the dozer cleared soil was more compact and poorly drained as evidenced by water ponding in a soil pit at the site. Roto-cleared soil generally had less moisture available for trees (Figures 5-7). The soil moisture seemed to have no relationship to amount of irrigation, but was somewhat related to biomass; with larger trees and greater amount of weed growth on the roto-cleared soils related to lower soil moisture. Soil moisture was higher at 30-40 cm depth in the soil than at the surface (Figures 8-9).

The lower soil moisture content on the roto-cleared soil was perhaps because of the better drainage and greater plant biomass removing water from the soil. Water in this soil was likely less tightly held since this soil was considerably less compact. All these conditions apparently favored growth of aspen trees.

Water Chemistry:

Data from 2006 confirmed that local pond water used for irrigation was saline. Non-saline potable water from a Hayden, CO, hydrant was used to irrigate the trees in 2007. Carryover of effects of saline irrigation water for 2005-2006 was evident in lower growth of aspen in the high and medium irrigation treatments compared to the low and control treatments.

Physiological status:

Initial analyses indicate that soil type and weed competition affected rate of photosynthesis and respiration. Highest rates of photosynthesis seemed to be in the weeded plots on roto-cleared soils, suggesting that these conditions are best for aspen growth and survival. Plant top and root growth on these plants would seem to verify that finding. Plant water status measurements indicated that when these tests were conducted during the 2007 growing season (June 28 and August

1) the plants were not water stressed, with pre-dawn leaf water potential pressures not exceeding 10 bars and most often less than 5 bars (Figures 10-11).

Root growth:

Root growth of transplants was best in weeded plots on roto-cleared soil and lateral roots extended far from the base of the original tree (Figures 12). They were of sufficient size (4 mm or more) where suckering could begin, but many were too deep (15 cm or deeper), a result of the deep planting of the transplanted trees. Trees in other treatments are surviving and roots are extending out, but it will take additional years for most to obtain sufficient size at depths necessary for suckering. In any case, suckers are more likely to appear after injury or death of parent trees when apical dominance is inhibited. Roots growing from the potted trees were mostly confined to the potting hole. This was also true for some of the transplants on dozer-cleared soil, perhaps a result of the high density and compaction of this dozer cleared and stored soil.

Depth of the roots systems for the transplanted aspen ranged from about 15 to 40 cm, with transplants in the roto-cleared soil planted somewhat deeper than those on the dozer cleared soil. These depths are too deep to allow effective suckering. Even though roto-cleared trees were planted somewhat deeper than dozer-cleared trees, growth was better on the roto-cleared trees. It is expected that trees planted deep will take longer to produce roots at a depth conducive to suckering, but those deep planted trees that survived are now producing shallower roots. Lateral root systems were already developing on most of the transplanted trees, and roots were observed near the surface several meters from the base of some trees suggesting that these trees were becoming well established. Apical dominance of the rapidly growing transplanted trees likely prevented suckering of these lateral roots. It is expected that enough root system has developed that further irrigation of these trees is not necessary.

Competing vegetation:

Weeds were an important competitor for soil moisture in the planted aspen plots. Soil moisture was higher in the weeded plots, suggesting more soil moisture available for tree growth in these plots (Figure 4). Weeding was particularly important for survival of natural sprouts occurring from residual aspen roots in the replaced topsoil. Trees growing on weeded plots grew considerably better and had higher rates of survival. Of 34 natural sprouted trees initially marked for study on the roto-tilled fresh soil in year 1, half were weeded and half un-weeded in years 2 and 3. All of the weeded trees survived into year 3 while only 4 of the un-weeded trees survived the first three years of the experiment. Of the 21 natural sprouts on the dozer-cleared stored soil, 8 of the 11 weeded trees but only 2 of the 10 un-weeded trees survived after 3 years. Most of the vegetative competition consisted of annual herbs, perennial grasses, and weed species. Weed present were primarily various thistle species. Shading was not a factor, since the trees were larger and growing above the competing vegetation canopy. The soil moisture data suggest competition between surface vegetation and trees for a limited amount of available water.

Conclusions:

Irrigation:

Best growth and survival was with low or no irrigation, but salinity of irrigation water in the first two years of the experiment reduced growth of trees receiving high and medium amounts of irrigation. Reclaimed soils were not saline, but salinity levels were high enough in irrigation water from local ponds to reduce growth of aspen. Care must be taken to provide low saline water when irrigating planted aspen trees on reclaimed lands. Low level irrigation and no irrigation growth and survival were similar, suggesting that enough rainfall and soil moisture occurred for the years this experiment so that irrigation was not necessary. It is expected but not tested in this experiment, that supplemental irrigation with clean water may have increased growth and survival above non-irrigated trees. It is expected that all surviving trees now have developed enough root system after three years that further irrigation is not needed.

Plant source:

Transplanted trees from local sources grew best once established. Most natural suckers did not survive without weeding. Potted plant had a high rate of survival, but growth was lower then for transplants and natural sprouts. Roots of potted aspen general stayed in the augured potting hole. This also occurred for a few of the transplanted trees in the more compact stored dozer cleared soil on the irrigation treatment plots, the same soil type where this occurred for the potted plants.

Soil type:

Best growth and survival occurred on roto-cleared (fresh) soil compared to dozer cleared (stored) soil. More natural sprouts from residual root segments were evident in roto-cleared soil. It is expected that higher number of natural sprouts was due to the shorter length of soil storage and the soil characteristics rather than the clearing method. The dozer cleared soil appeared to be more compacted and was less well drained than the roto-cleared soil, and it is expected that these physical characteristics were more important to tree growth than the method of clearing. Also, storage effects on the soil were likely more important than method of clearing.

Weed control:

The best growth of aspen was with trees that were weeded. This was likely related to lower water stress of the trees, since weeds competed with the trees for the limited water supply. This was particularly apparent on the roto-cleared soils where weed competition was high.

Root growth:

Similar to top growth, root growth was greater in weeded plots compared to un-weeded plots on the roto-cleared soil. Effect of weeding on root growth of dozer cleared soils was less evident, likely since weed competition was considerably less and growth was less on the dozer cleared soils. Roots in most treatments were of

sufficient size but too deep to support suckering. Nevertheless, sucker initiation was likely inhibited by apical dominance of the growing trees. Lateral root extension was progressing, but was considerably slower in the un-weeded plots and on the dozer cleared soils. The upward growth of roots toward the soil surface that was observed indicates that care should be taken in future plantings to plant trees only to a depth of the original root collar.

Overall recommendation:

Best conditions for reproduction of aspen on reclaimed surface mined coal lands is by using transplanted saplings from local sources on freshly placed soil removed from aspen stands. Care should be taken to avoid compaction of the replaced soil. Transplanted trees should be planted no deeper than the original root collar, and weeds should be controlled around individual trees. Irrigation with non-saline water might enhance growth and survival in years with drought conditions.

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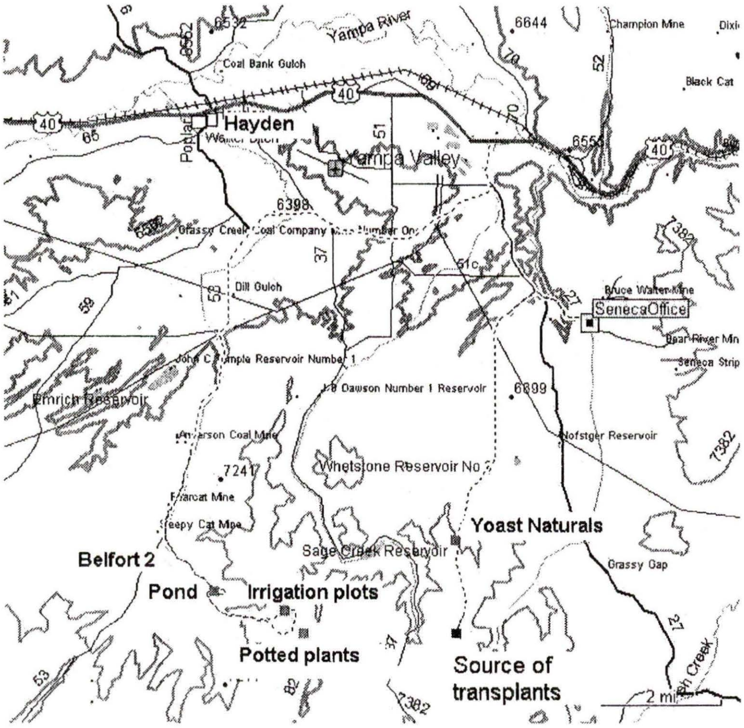

Figure 1. Map of experimental plot location, Seneca Coal Mine, Hayden, CO.

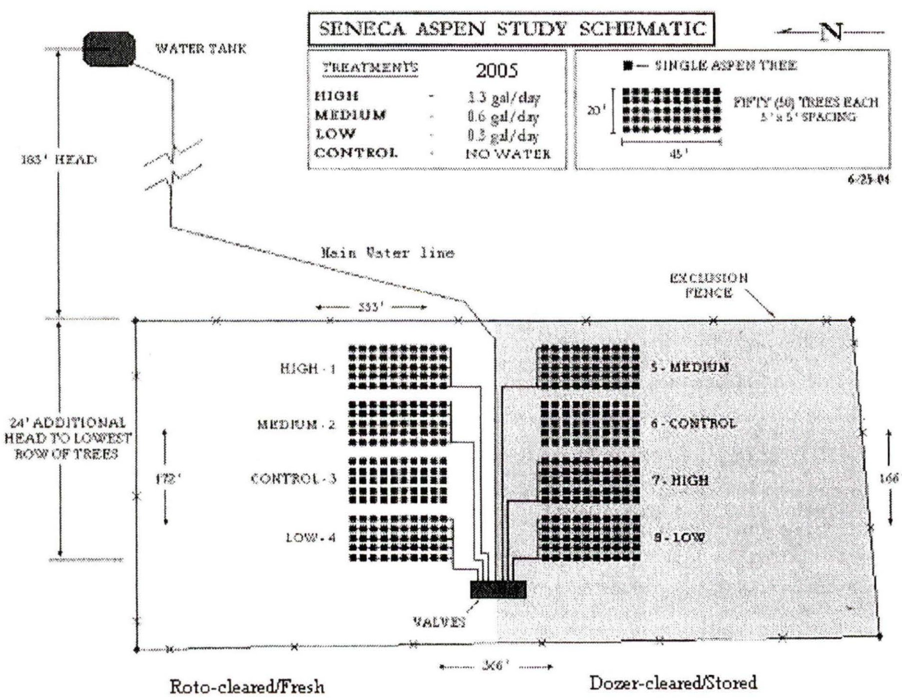

Figure 2. Experimental design for aspen reclamation project, Seneca Coal Mine, Hayden, CO.

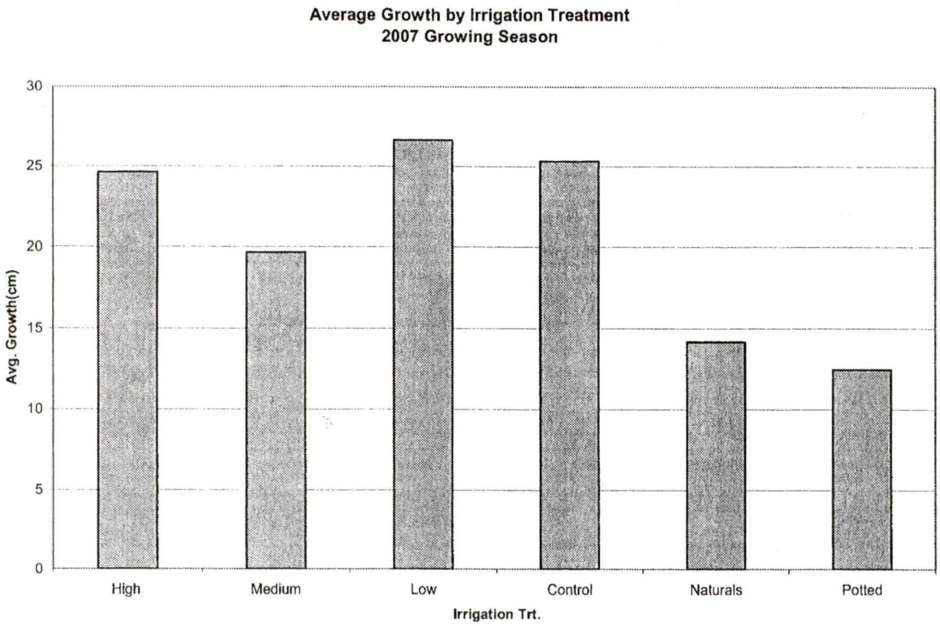

Figure 3. Average growth, cm, by irrigation treatment. Controls, naturals and potted trees were not irrigated.

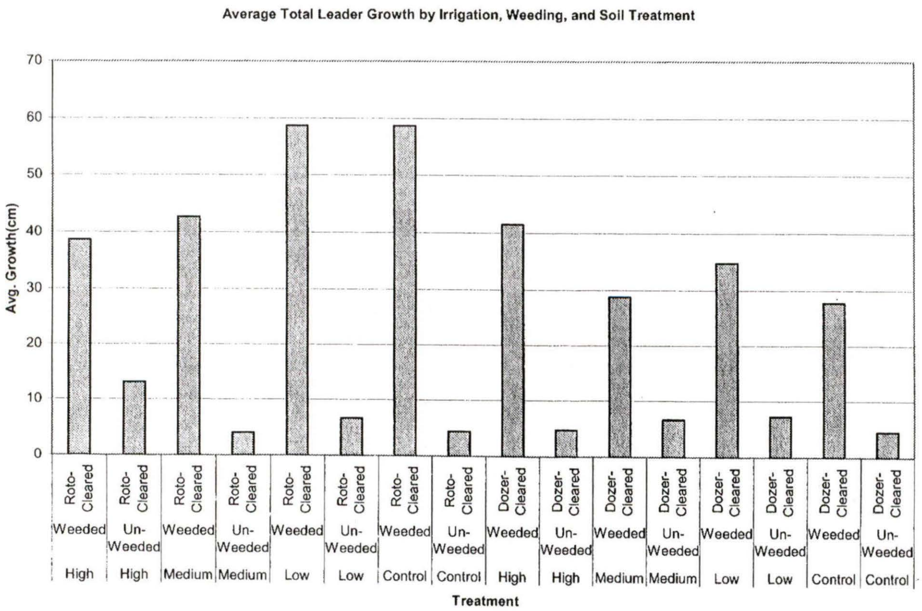

Figure 4. Average growth in cm by irrigation, weeding, and soil type.

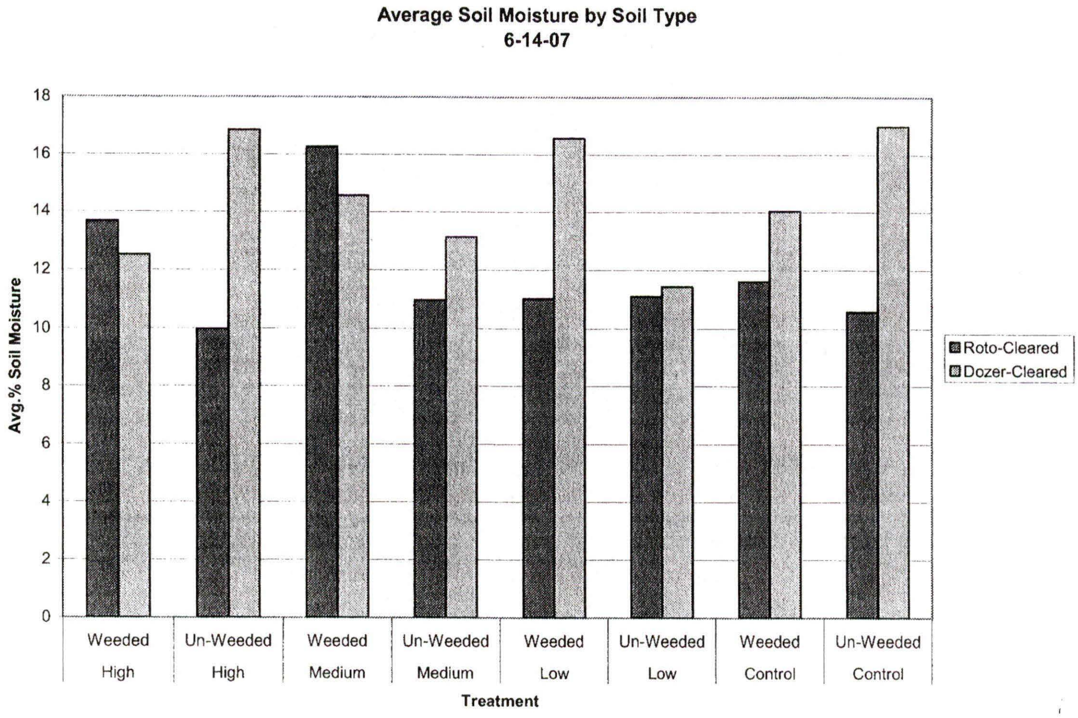

Figure 5. Average soil moisture by soil type and weeding treatment, June 14, 2007.

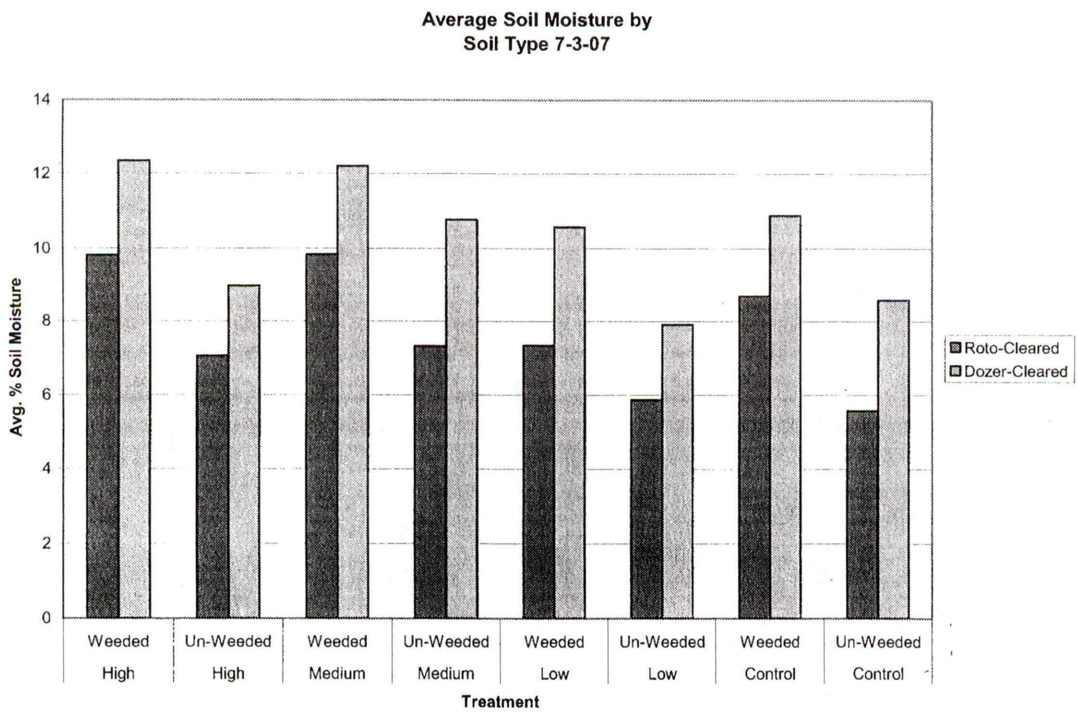

Figure 6. Average soil moisture by soil type and weeding treatment, July 3, 2007.

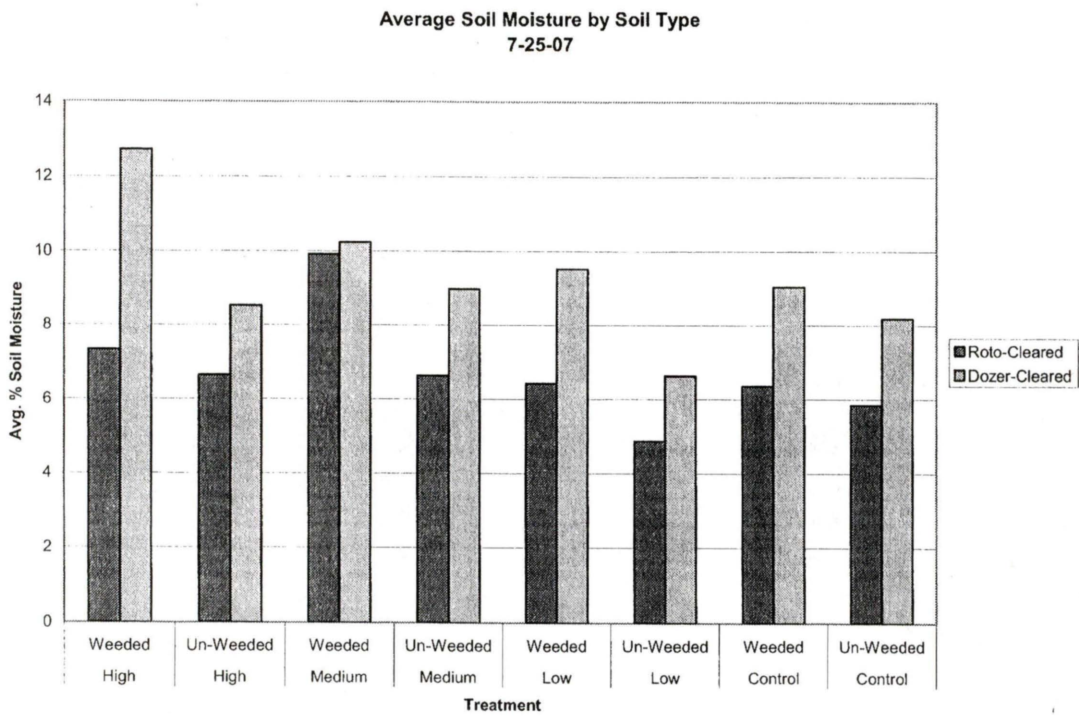

Figure 7. Average soil moisture by soil type and weeding treatment, July 25, 2007.

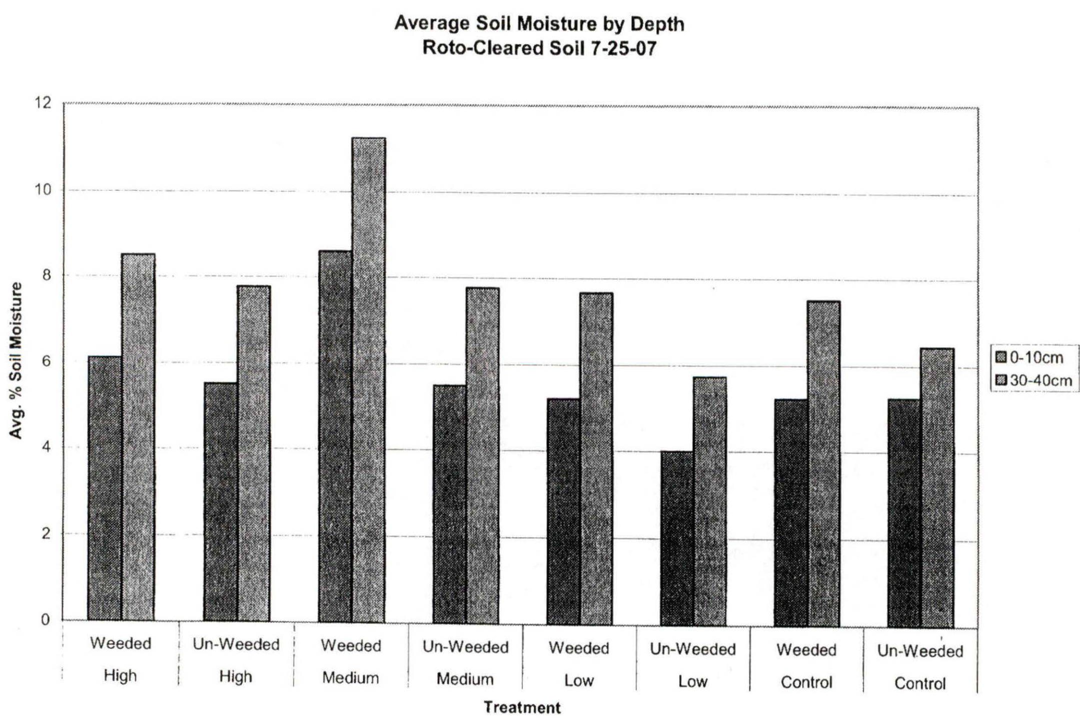

Figure 8. Average % soil moisture by depth, roto-cleared soil.

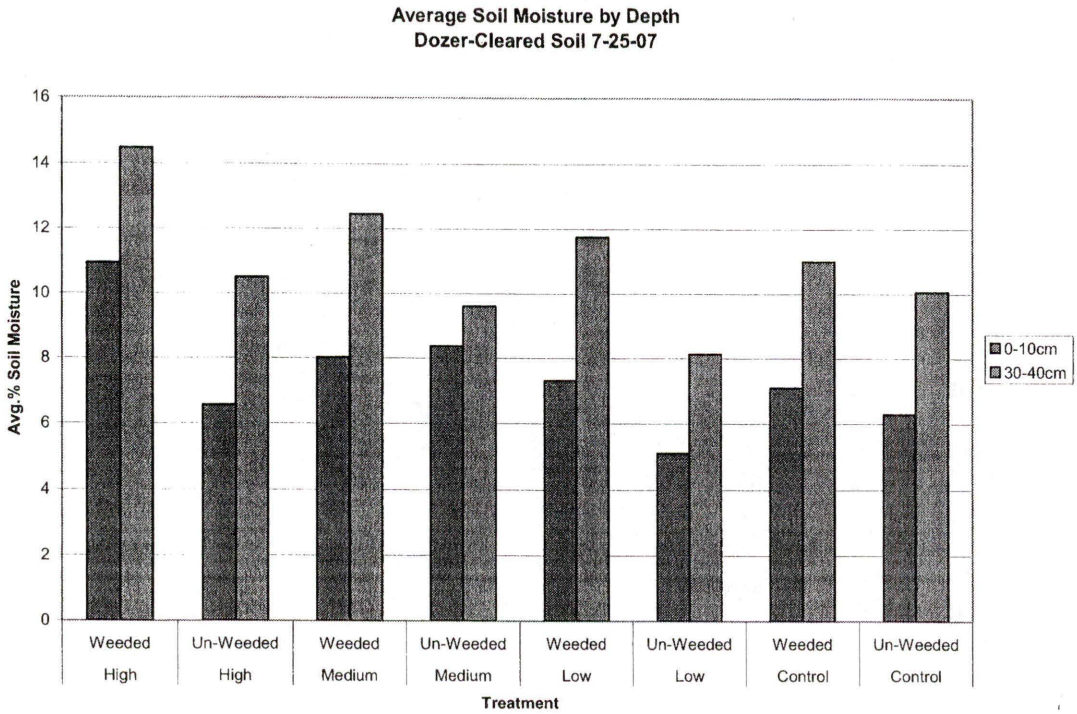

Figure 9. Average % soil moisture by depth, dozer cleared soil.

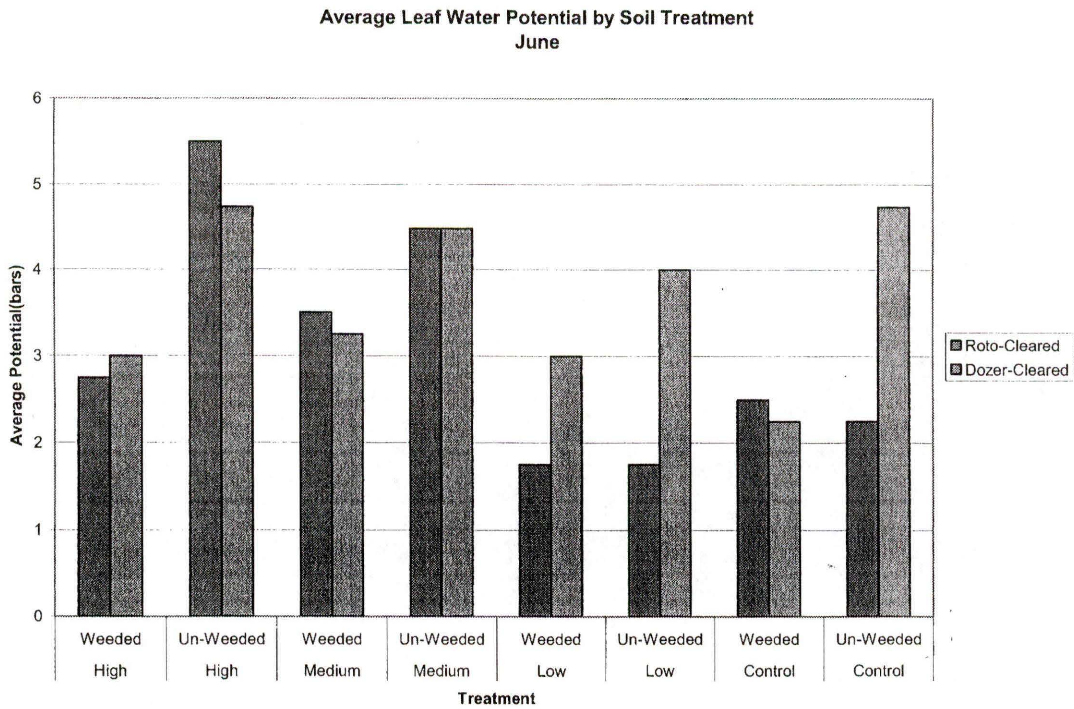

Figure 10. Average pre-dawn leaf water potential, June 28, 2007.

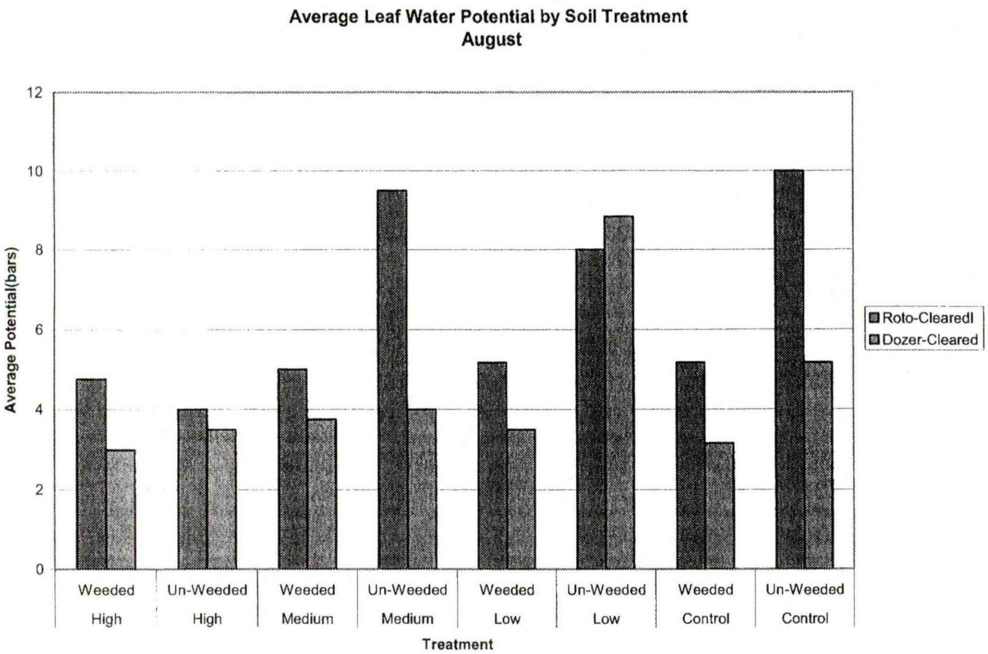

Figure 11. Average pre-dawn leaf water potential, August 2007.

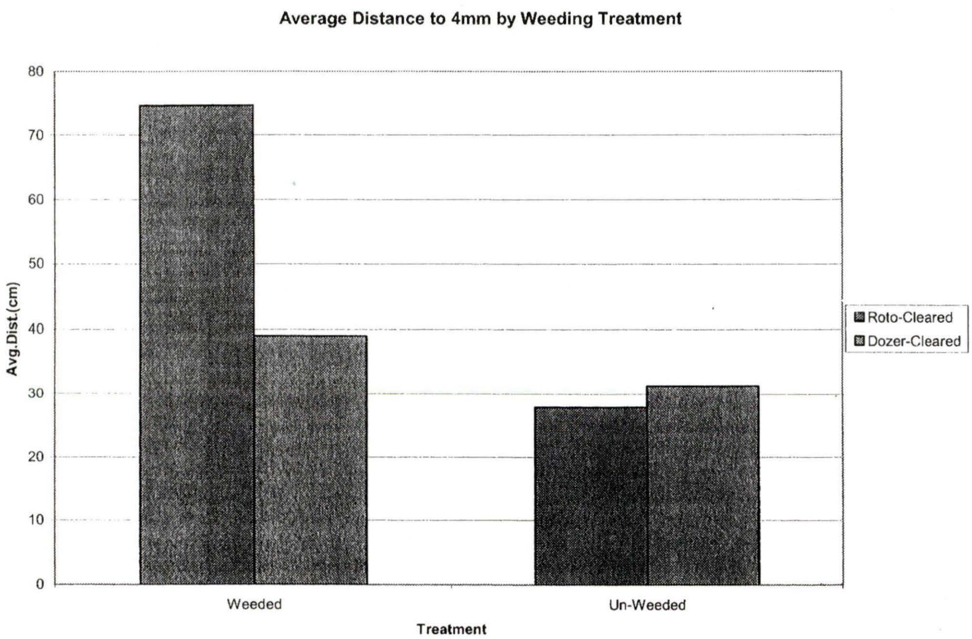

Figure 12. Average distance in cm of root extension from base of tree to 4 mm root diameter.